

RESEARCH PAPER

What Makes a Dog? Stable Isotope Analysis and Human-canid Relationships at Arroyo Hondo Pueblo

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Domesticated animals in the prehispanic American Southwest/Mexican Northwest functioned in many roles, but these roles seem to have varied across time and space. In this study, we use bone collagen and apatite carbon ($\delta^{13}\text{C}_{\text{col/ap}}$) and nitrogen ($\delta^{15}\text{N}$) stable isotopes to investigate the role(s) of seven canids from Arroyo Hondo Pueblo (LA 12), a 14th century site in the northern Rio Grande, New Mexico. Results indicate that in some cases, coyotes seem to have been treated like dogs; in others, dogs seem to have been treated like their wild relatives. In all cases, canids were treated differently than domestic turkeys. We conclude that ethnographic, genetic, geochemical and site-specific contextual data are required to understand the roles of dogs and wild canids in Ancestral Puebloan contexts.

Social Media: New isotopic data, combined with previously published provenience and aDNA information, suggest different classifications of canids by Ancestral Puebloans at Arroyo Hondo Pueblo.

Keywords: Canids; domestic dogs; stable isotopes; Ancestral Puebloan; Southwestern archaeology; New Mexico

Introduction

Domestication can be defined in multiple ways, particularly as applied to domestic animals (e.g., Driscoll et al. 2009; Price 1984; Russell 2002; Zeder 2012). Traditionally, zooarchaeological documentation of animal domestication has focused on the markers of genetic change in response to human involvement in the breeding process (see discussion in Zeder 2006); commonly-cited evidence of this process includes morphological markers (such as change in size), non-morphological indicators of management (such as demographic profiles), zoogeographic data (particularly on abundance), and other indicators of human control (such as pens). Such data are increasingly used in association with archaeogenetic data (Bradley 2006), which has led to sophisticated, multi-method investigations of domestication (e.g., Hu et al. 2014; Patel and Meadows 2017; Prendergast et al. 2017; Sharpe et al. 2018; Thornton et al. 2012; individual chapters in Zeder et al. 2006).

However, different societies define “domestic” differently (e.g., Lins Neto et al. 2014). Animal domestication suggests a change in the human-animal relationship, but how this change manifests in a particular group, and thus in the archaeological record, will vary (for example, Chevallier 1987; Vijayakumar et al. 2015). In archaeological studies of domestic animals, there is always the potential for discrepancy between archaeological definitions

of domestication and those of past societies (Losey et al. 2011; Monagle in press). The potential for disjuncture in definitions of domestication is particularly present in the case of domesticated dogs (*Canis familiaris*). Dogs are genetically distinct from their canid relatives, but they assume multiple roles in human society (Frantz et al. 2016; Larson et al. 2012; Morey 1994; 2006; Serpell 1995), and some wild canids (both coyotes, *Canis latrans*, and wolves, *Canis lupus*) have been tamed and kept in captivity (Koler-Matznick 2002), and some archaeologists (i.e., Losey et al. 2011) have identified situations in which wild canids appear to have played a role more commonly assigned to domestic animals after death.

We know that animals played a variety of roles within Ancestral Puebloan societies in the prehispanic American Southwest (e.g., Ainsworth et al. 2018, Jones et al. 2015, Tyler 1975, Tyler 1979), making the consideration of disjunctures in domestication definitions particularly important in this region. Two clearly domestic species were present in the prehispanic Southwest: turkeys (*Melagris gallopavo*) and dogs. Studies of these two taxa have been used to support arguments for larger population movements within the greater Southwest (Kemp et al. 2017). Both dogs and turkeys were recovered at Arroyo Hondo Pueblo (LA 12), a 14th century pueblo in northern New Mexico (Lang and Harris 1984). While the turkeys of Arroyo Hondo are well-studied (Conrad et al. 2016), the role of domestic dogs at this site is less clear. Dogs can be difficult to distinguish from coyotes (*Canis latrans*) based on skeletal morphology alone (Calaway 2001; Howard 1949; Krantz 1959). While 71 bones from canid specimens were recovered at Arroyo Hondo Pueblo, most were

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not identifiable to species and only 22 could be positively identified as dog (Lang and Harris 1984). However, many of these canids were recovered from within architectural deposits (including from within kivas) – a method of deposition often associated with species that served a function after life, which in the Southwest is more commonly associated with domestic dogs than with coyotes (Hill 2000). This suggests some of the Arroyo Hondo canids may be domestic dogs. Conversely, a recent genetic analysis found that some of the specimens originally identified as dogs at Arroyo Hondo are genetically coyotes (Kemp et al. 2017). The status of dogs and other canids at Arroyo Hondo is clearly in need of investigation.

Stable isotopes can be used to assess human-canid relationships in the past, particularly the degree of human influence on canid diets (Guiry 2012; 2013), making this one potential way to address the seeming contradiction between the zooarchaeological analysis and the deposition of canids at Arroyo Hondo Pueblo. In this paper, we use new stable isotope data in conjunction with previously-published data on burial treatment and context to explore how the prehistoric inhabitants of Arroyo Hondo saw these individual canids. Partway through our study, a publication on the mtDNA of some of these specimens was released (e.g., Kemp et al. 2017); we incorporate these published data into our analysis as well. While Kemp and colleagues also published some isotope data on the Arroyo Hondo canids, we do not consider those results here; rather, as our study was designed and completed completely independently, we present our data as

an additional line of evidence into canid feeding ecology at Arroyo Hondo Pueblo.

The Canids of Arroyo Hondo Pueblo

Arroyo Hondo Pueblo (**Figure 1**), an Ancestral Puebloan archaeological site located 5 miles southeast of Santa Fe and dated between A.D. 1300 and 1420, was extensively excavated by the School of American Research (currently School for Advanced Research) in the early 1970s (Lang and Harris 1984; Wetterstrom 1986). Diets of Arroyo Hondoans seem to have consisted of a mix of maize (*Zea mays*), beans (*Phaseolus vulgaris* L.), squash (*Cucurbita pepo* L.), and wild plants, as well as mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*), lagomorphs (both jackrabbits, *Lepus* sp., and cottontails, *Sylvilagus* sp.), and domestic turkeys (Lang and Harris 1984; Wetterstrom 1986). Other animal taxa recovered at Arroyo Hondo included elk (*Cervus elaphus*), bison (*Bison bison*), hawks (family Accipitridae), bear (*Ursus* sp.), squirrels (family Sciuridae), geese (family Anatidae), turtles (order Testudines) and scarlet macaws (*Ara macao*).

Relevant to this study, 22 domestic dog (*Canis familiaris*) specimens and 49 specimens identified as *Canis* spp. (which may include wolves as well as coyotes and domestic dogs) were also identified at Arroyo Hondo Pueblo (Lang and Harris 1984:87). The incompleteness of these specimens and their relatively low number led the original analysts to suggest domestic dogs were rare at the Pueblo, perhaps due to the risk these animals might pose to turkeys (Lang and Harris 1984:88). While these canid

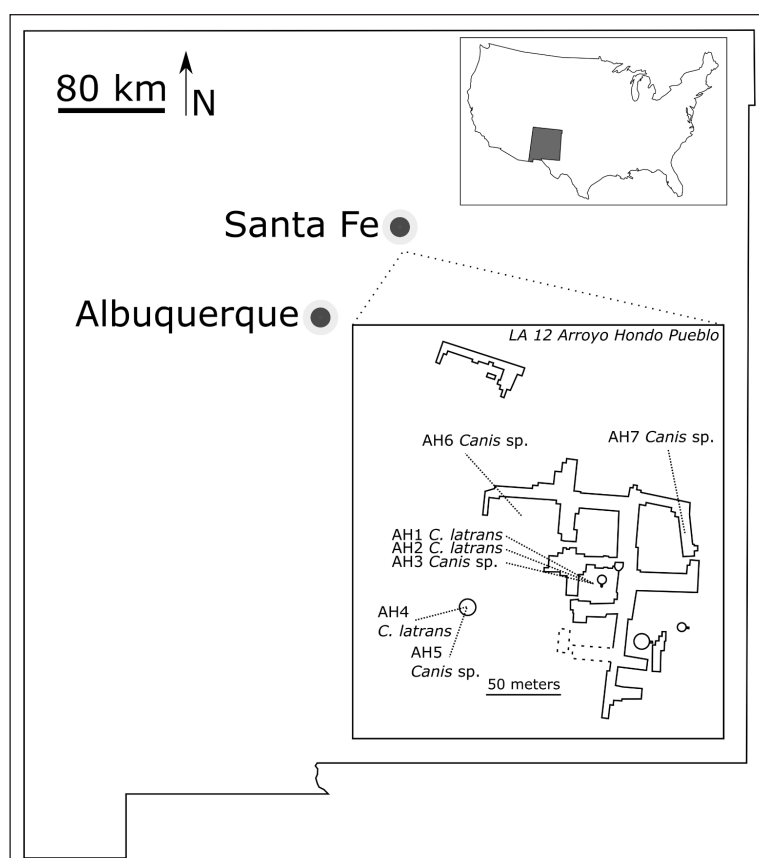


Figure 1: Arroyo Hondo Pueblo and provenience of canids analyzed in this study.

specimens were recovered from a number of different contexts at Arroyo Hondo, some were associated with architectural features, and thus may have been simple interments or dedicatory offerings (Hill 2000). Canids treated this way are, we argue, more likely to have been domestic dogs than coyotes. Through the process of domestication, dogs developed behaviors that allowed for them to exist alongside humans, occupying a social role that wild canids, such as wolves and coyotes, could not fill (Morey 2010). Ethnographic and ethnohistoric sources discuss Southwest dogs filling social roles such as guardians, trash-eaters, and pets (e.g., Bolton 2003; Bourke 1884; Frisbie 1967; Lomatuway'ma, et al. 2001; Parsons 1939; Stephen 1929; Winship 1904). Dog burials in the Southwest are relatively common, and are typically interpreted as reflecting social relationships and roles filled within communities during and after life (Hill 2000). In contrast, in ethnographic sources wild canids are depicted as sorcerers, predators, competition for humans, and tricksters (e.g., Flores 2016; Lomatuway'ma, et al. 2001; Mills and Walker 2008; Parsons 1939; Walker 1998) – unlikely candidates for burials in kivas or domestic spaces.

The Arroyo Hondo canid specimens considered here (NISP = 7, MNI = 6; see **Table 1**) were recovered from kivas, plazas, and roomblocks (**Figure 1**), suggesting these animals had social roles within the Arroyo Hondo community. One cluster of canid remains (specimens AH4 and AH5) were recovered from a kiva, and identified as having possibly received “preferential treatment upon death”, as they were represented not just by a single element but included a tibia, femur, vertebra, and skull fragment (Lang and Harris 1984:89). Although the other Arroyo Hondo canids are represented by specimens in a variety of locations, this does not weaken the argument that these specimens filled a special role before and/or after death. Canid burials in the Southwest are highly variable and while many interments and dedicatory offerings contain complete canid skeletons and/or skulls, a majority are defined simply by their associations with an architectural feature such as kiva, plaza, or room block floor (Hill 2000).

In this context, the Arroyo Hondo canids present a puzzle: while the original analysis indicated they were likely predominantly coyotes, the burial locations of the seven individuals considered here suggest these canids had a role within the Arroyo Hondo community that would more

likely have been filled by domestic dogs than coyotes. Ancient mtDNA from these canids further complicates the picture: three of the seven specimens analyzed in this paper, including the canid identified as having been given “preferential treatment”, have mtDNA suggesting that their maternal line, at least, was coyote (**Table 1**); an additional three canid specimens recovered from architectural features at Arroyo Hondo also had coyote mtDNA (Kemp, et al. 2017).

The contradiction between the burial context and mtDNA data at Arroyo Hondo requires explanation. Are the four still-unidentified canids in our sample dogs or coyotes? Do the specimens that are genetically coyotes represent wild canids with a social role within the Pueblo, or does their recovery location represent something more prosaic such as trash disposal?

Isotopes and human-animal relationships

Isotopic analysis, particularly carbon and nitrogen isotope data and carbon apatite-collagen spacing, can provide information on dietary patterns during life and help determine lifetime proximity to humans through subsistence sourcing and levels of human management (e.g., Rick, et al. 2011). These techniques may help to resolve the questions of canid roles at Arroyo Hondo Pueblo.

Carbon isotopes

The analysis of stable carbon isotopes ($\delta^{13}\text{C} = ^{13}\text{C}/^{12}\text{C}$) in animal tissues provides the ability to understand the types of plants and/or animals that individuals consumed during their lifetime (DeNiro and Epstein 1978). Plants assimilate stable carbon isotopes in carbon dioxide during photosynthesis: some plants (including many shrubs common in New Mexico) follow a C_3 photosynthetic pathway, while others (including maize but also many grasses native to the Western US) use C_4 (e.g., Kohn and McKay 2012). Herbivorous animals are primary consumers and omnivorous animals are both primary and secondary consumers; as the isotopic signature of the consumed resource is incorporated into the tissue of the consuming animal, it is often possible to identify what types of plants formed the basis of the animal diet. In the prehispanic Southwest, domesticated maize (a C_4 plant) formed the basis of most Puebloan diets (e.g., Coltrain, et al. 2007, Cordell and McBrinn, 2012, Geib 2011, Matson and Chisholm 1991, Swarts et al. 2017), but many Southwest mammalian and

Table 1: Canids from Arroyo Hondo analyzed in this study. “Taxon (ZA)” indicates our identification, which was based on morphological characteristics alone. *After Kemp et al. (2017).

Sample ID	Taxon (ZA)	Taxon (mtDNA)*	Recovery Location
AH1	<i>Canis</i> sp.	<i>Canis latrans</i>	Plaza G or Kiva (12-G-ST1-1)
AH2	<i>Canis</i> sp.	<i>Canis latrans</i>	Plaza G or Kiva (12-G-ST1-1)
AH3	<i>Canis</i> sp.	<i>Canis</i> sp.	Plaza G or Kiva (12-G-ST1-1)
AH4	<i>Canis</i> sp.	<i>Canis latrans</i>	Kiva J (12-J-1)
AH5	<i>Canis</i> sp.	<i>Canis</i> sp.	Kiva J (12-J-1)
AH6	<i>Canis</i> sp.	<i>Canis</i> sp.	Plaza H (12-H-3-8)
AH7	<i>Canis</i> sp.	<i>Canis</i> sp.	Roomblock 11 (12-11-3-6)

avian fauna consumed C_3 resources (Cormie and Schwarcz 1994; 1996; Fair and Heikoop 2006). In this context, $\delta^{13}C$ values can provide a window into the degree to which an animal had access to maize.

Nitrogen isotopes

Nitrogen isotope ratios ($\delta^{15}N = ^{15}N/^{14}N$) provide a means to understand trophic scale relationships between producers and consumers (DeNiro and Epstein 1981). Due to enrichment of nitrogen isotopes in consumers relative to the resource being consumed, animals have more positive nitrogen isotope ratios than their diets. Analysis of nitrogen stable isotopes in prehistoric societies is useful for determining various levels of anthropogenic dietary influence in animals since humans often influence $\delta^{15}N$ values in their immediate landscape (Bogaard et al. 2007; Finucane 2007; Szpak 2014). However, it is important to note that $\delta^{15}N$ values may be impacted by variables including animal age, weaning status, prey body size, environmental conditions, and the presence of nitrogen fixing plants (Handley and Raven 1992; Minagawa and Wada 1984; Steele and Daniel 1978; Ugan and Coltrain 2011).

$\delta^{13}C$ Apatite-Collagen spacing

Stable carbon isotope spacing between bone apatite and collagen can be used to identify how organisms consume macronutrients (e.g., Bartelink 2009; Eerkens et al. 2013), as bone collagen records dietary protein components (Ambrose et al. 1993) and bone apatite represents bulk dietary components (protein, carbohydrates, and fats; Krueger and Sullivan 1984). Spacing values therefore provide a proxy for whether individual animals consumed the same types of resources for their protein, carbohydrate and fat dietary components (see, for example, Lee-Thorp et al. 1989). Variable spacing, or differences in the carbon isotope composition of protein relative to bulk protein, carbohydrates and fats, suggests specific types of resources were consumed for certain macronutrients versus others. For example, identification of variable spacing in domesticated turkeys from Tijeras Pueblo (LA 581) suggested that while turkeys consumed C_4 plants (likely maize), wild C_3 resources (likely insects in maize fields) comprised the bulk of the protein component of their diet (Jones et al. 2016).

Isotopes and canid roles

Previous research on $\delta^{13}C$ and $\delta^{15}N$ in canids suggests coyotes and domestic dogs should have distinct isotopic signatures. Coyotes are generalist omnivores and consume a wide diversity of resources depending on regional population density, prey abundance, competition, and anthropogenic influence (Ames, et al. 2015; Coltrain et al. 2004; Murray, et al. 2015; Rose and Polis 1998; Schoeninger 1985; Schwarcz 1991; Warsen, et al. 2014). Three modern coyotes recovered from sites in California and Mexico exhibited $\delta^{13}C$ values of -19.3‰ , -18.6‰ , and -11.7‰ with similarly diverse $\delta^{15}N$ values of 8.0‰ , 5.7‰ , and 18.8‰ (Schoeninger 1985). In contrast, previously identified domesticated dog stable isotope values ($n = 5$) in the American Southwest and Mexican Northwest have $\delta^{13}C$ values ranging between -7.6‰ and

-11.0‰ and $\delta^{15}N$ between 6.7‰ and 9.0‰ (Katzenberg 1991; Kellner, et al. 2010; Martin 1999; Spielmann, et al. 1990; Webster and Katzenberg 2008; personal communication R. Tykot, 2017).

This previous research provides clear predictions for the Arroyo Hondo canids. We expect canids excavated from burial contexts within architectural features to exhibit $\delta^{13}C$ and $\delta^{15}N$ stable isotope data that reflects diets consistent with human management. Canids that fulfilled a community role at Arroyo Hondo Pueblo could be expected to have had diets similar to those of domesticated dogs, turkeys, and Ancestral Puebloan populations from the Northern Rio Grande (see Conrad, et al. 2016; Kellner et al. 2010; Spielmann, et al. 1990), all of which show enriched ^{13}C reflecting a diet focused on C_4 plants (likely maize), as well as close clustering of $\delta^{13}C$ and $\delta^{15}N$ values (see Rawlings and Driver 2010). Conversely, if the coyotes and unidentified canids in our sample represent trash disposal and were not treated as members of the Arroyo Hondo community, we would expect them to exhibit $\delta^{13}C$ values suggesting C_3 -based diets and variable $\delta^{15}N$ values.

Methods

We sampled seven canid specimens from Arroyo Hondo (Table 1), analyzing bone collagen ($\delta^{13}C_{col}$ and $\delta^{15}N$), bone apatite ($\delta^{13}C_{ap}$), and $\delta^{13}C$ collagen-apatite spacing. Our sample consisted of specimens identified as canids by Lang and Harris and located by Robin Lyle (Lang and Harris 1984; Robin Lyle, personal communication). It included both adult and juvenile canids, a fact important to note as juveniles may have elevated $\delta^{15}N$ values due to trophic level enrichment via nursing (e.g., Fuller, et al. 2005; Guiry 2012; Schurr 1998).

Collagen sample preparation and analysis

Using a Dremel saw, we cut a non-diagnostic 50–100 mg bone fragment from each specimen for collagen analysis. These samples were i) demineralized in 0.5 N hydrochloric acid for 24 hours at $5^\circ C$, ii) rinsed to neutrality and lipid-extracted using a solution of 2:1 chloroform/methanol for 24 hours (repeated three times), and iii) rinsed to neutrality and lyophilized for 24 hours. After lyophilization 0.5–0.6 mg of sample was weighed into tin capsules for stable carbon ($\delta^{13}C_{col}$) and nitrogen ($\delta^{15}N$) analysis at the University of New Mexico Center for Stable Isotopes (UNM-CSI). Carbon and nitrogen values were measured using a Costech (4010) elemental analyzer coupled to a Thermo Scientific Delta V isotope ratio mass spectrometer. Isotope data are expressed in delta (δ) notation as: $[(R_{sample}/R_{standard}) - 1] \times 1000$, where R_{sample} and $R_{standard}$ are the ratios of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ in the sample and standard. Isotope samples were analyzed using the internationally accepted standards of Vienna Pee Dee Belemnite (V-PDB) limestone and atmospheric N_2 for $\delta^{13}C$ and $\delta^{15}N$. All δ values are reported as parts per thousand (‰). Atomic weight carbon to nitrogen concentrations ranged between 3.1 and 3.3 (Table 3), indicating unaltered and preserved collagen (Ambrose 1990). Analysis of internal reference standards provided analytical precision (SD) of $<0.22\text{‰}$ for $\delta^{13}C$ and $\delta^{15}N$.

Apatite sample preparation and analysis

We used a Dremel drill to homogenize 50–100 mg of bone for apatite carbon isotope ($\delta^{13}\text{C}_{\text{ap}}$) analysis. Each sample was washed with 3% hydrogen peroxide for 24 hours to remove organics, then rinsed to neutrality two times using deionized water. To remove labile diagenetic carbonate, we treated the samples in 0.1 M buffered acetic acid for 30 minutes (Coltrain and Janetski 2013), then rinsed the samples to neutrality three times using deionized water. Treated bone apatite was dried for 24 hours under a fume hood and then 5–10 mg of bone powder was weighed into glass exetainer vials and treated with phosphoric acid at 50°C for 6 hours to produce CO_2 prior to isotope analysis. Apatite analysis occurred on a Thermo Scientific GasBench coupled to a Delta V isotope ratio mass spectrometer at UNM-CSI. Isotope values and delta calculations match bone collagen techniques described above. Analysis of internal reference standards provided analytical precision (SD) of $<0.11\text{‰}$ for $\delta^{13}\text{C}_{\text{ap}}$.

Apatite-collagen spacing

We use $\delta^{13}\text{C}$ apatite-collagen spacing to identify anthropogenic feeding versus foraging in the Arroyo Hondo canids. If the Arroyo Hondo canids were fed by the human inhabitants of Arroyo Hondo Pueblo, their diets should have been heavy in C_4 (likely maize), as human diets were (Palkovich 1980). In this case both the apatite (protein/carbohydrates/fats) and collagen (protein) fraction of bone should indicate the presence of a C_4 -heavy diet and, correspondingly, enriched $\delta^{13}\text{C}$. In contrast, we expect canids without access to maize to have depleted $\delta^{13}\text{C}$ bone apatite and collagen C_3 values, reflecting a diet comprised of C_3 plants and herbivores, as has been recorded for other omnivorous canids; previous research on such canids suggests apatite-collagen spacing of approximately $+5.2\text{‰}$ (Krueger and Sullivan 1984; Lee-Thorp et al. 1989). Finally, canids with varied diets, as might be expected in the case of animals with access to maize or maize-fed resources via scavenging, should exhibit more variable spacing with enriched bone apatite and depleted bone collagen (as in Jones et al. 2016). In short, following identified regression models (i.e., Kellner and Schoeninger 2007) we expect canids with C_4 -based protein (suggesting they were fed C_4 -fed meat sources) to fit the line $y = 1.71x + 10.6$ ($r^2 = 0.80$) and canids with C_3 -based protein (suggesting foraging) to fit the line $y = 1.74x + 21.4$ ($r^2 = 0.95$).

Results

Collagen analysis

The seven samples produced distinct and varied $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values (Table 2, Figure 2). The $\delta^{13}\text{C}$ values for *Canis* sp. range between -11.3‰ and -18.0‰ , and between -14.3‰ and -17.6‰ for canids identified as *Canis latrans*. The $\delta^{15}\text{N}$ values for *Canis* sp. range between 6.3‰ and 13.4‰ , and between 6.3‰ and 9.3‰ for *Canis latrans*. The *Canis* sp. sample from Plaza H (sample AH6) is enriched in bone collagen $\delta^{13}\text{C}$, and the *Canis* sp. sample from Roomblock 11 is enriched in $\delta^{15}\text{N}$ (sample AH7). Samples from Kiva J (samples AH 4 and 5), possibly representing a burial context, are virtually identical to each other in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ (Table 2) suggesting they may indeed derive from the same individual.

Apatite analysis

The seven canids produced similar $\delta^{13}\text{C}_{\text{ap}}$ values (Table 2). Samples identified as *Canis latrans* range between -7.9‰ and -9.5‰ , whereas the canids with no species identification range between -7.3‰ and -10.7‰ in $\delta^{13}\text{C}_{\text{ap}}$. The sample AH6 from Plaza H is enriched in $\delta^{13}\text{C}_{\text{ap}}$ (as it is in bone collagen). There is greater variation (0.8‰) in $\delta^{13}\text{C}_{\text{ap}}$ than in bone collagen from samples AH4 and AH5 in Kiva J (Table 2).

Collagen-apatite spacing

The samples are variable in bone apatite-collagen spacing values (Table 2; Figure 3). The average spacing is $+6.7\text{‰}$, but this encompasses a maximum value of $+9.4\text{‰}$ for the *Canis latrans* sample AH1 and a minimum value of $+4.0\text{‰}$ for the *Canis* sp. sample AH6. Samples AH1, AH2, and AH3, two coyotes and one *Canis* sp. specimen, have spacing values suggesting a diet with C_3 protein, while sample AH6 (*Canis* sp.) indicates a diet with a substantial contribution of C_4 protein. Samples AH4, AH5 and AH7 (a coyote and two *Canis* sp.) have intermediate values, suggesting mixed C_3/C_4 diets.

Discussion

These results have numerous implications for our understanding of human interactions with domesticated dogs and wild canids in the prehispanic Southwest. In the following discussion, we focus on three of these: 1) the use of stable isotopes to distinguish domesticated dogs from other canids; 2) the roles of canids in the Ance-

Table 2: Isotopic values of the Arroyo Hondo canid sample.

Sample ID	$\delta^{13}\text{C}_{\text{col}}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}_{\text{ap}}$	%C	%N	Weight% C:N	Atomic C:N
AH1	-17.3	9.3	-7.9	41.9	15.3	2.7	3.1
AH2	-17.6	9.3	-9.5	41.7	15.4	2.7	3.2
AH3	-18.0	8.5	-10.7	41.9	15.1	2.8	3.2
AH4	-14.3	6.3	-8.1	41.8	15.3	2.7	3.2
AH5	-14.4	6.3	-8.9	42.1	15.1	2.8	3.3
AH6	-11.3	11.2	-7.3	42.5	15.2	2.8	3.3
AH7	-16.0	13.4	-9.3	42.1	14.7	2.9	3.3

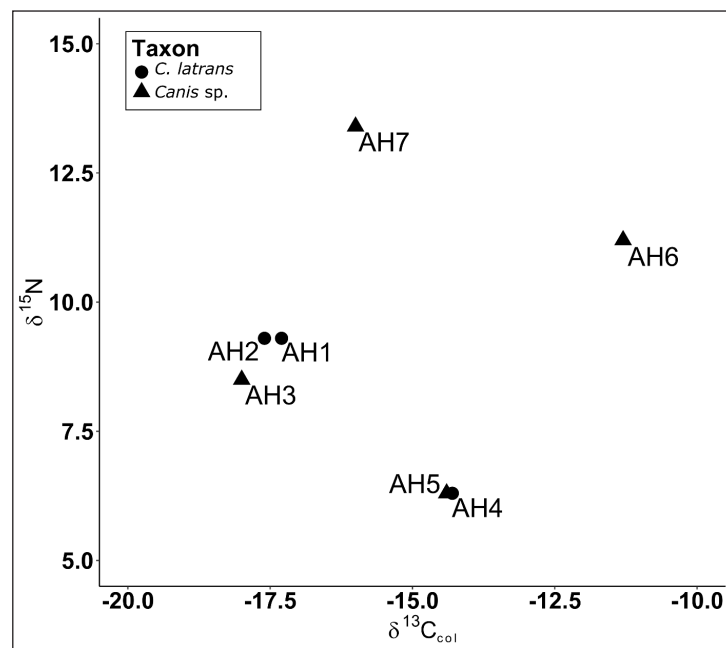


Figure 2: Collagen-derived $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of the specimens analyzed in this study.

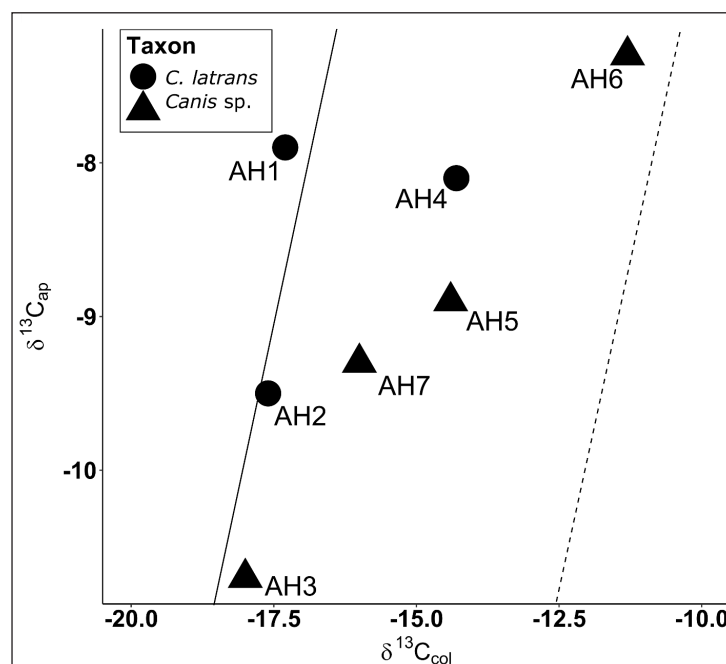


Figure 3: Collagen and apatite $\delta^{13}\text{C}$ values of the specimens analyzed in this study. The solid line represents C_3 protein sources and the dashed line represents C_4 protein sources (after Kellner and Shoeninger 2007).

tral Puebloan world; and 3) human-canid relationships and how they compare to relationships between other managed animals at Arroyo Hondo.

Dogs, wild canids, and stable isotopes

Our results, combined with those from other studies (Table 3), suggest that bone collagen and apatite stable isotopes are insufficient to distinguish between genetically domestic and wild canids. This is most clear in samples AH4 and AH5. These specimens likely derive from the same individual; isotopically, they are relatively enriched in $\delta^{13}\text{C}$ and depleted in $\delta^{15}\text{N}$ (suggesting a maize or other

C_4 plant-focused diet). However, sample AH4 is, according to its mtDNA, genetically a coyote (Kemp et al. 2017).

Arroyo Hondo is not the only site at which isotopic signatures for canids are unclear. Specimens identified as dogs through ancient DNA analysis from Albert Porter Pueblo and from Yellow Jacket Pueblo in southwestern Colorado have $\delta^{13}\text{C}$ (−18.6‰ and −15.9‰) and $\delta^{15}\text{N}$ (7.6‰ and 9.0‰) values matching those of wild canids (Kemp et al. 2017: Table 6). Conversely, a modern coyote specimen collected from a site in Mexico had $\delta^{13}\text{C}$ (−11.7‰) and $\delta^{15}\text{N}$ (18.8‰) values matching those of genetically domesticated dogs (Shoeninger 1985). This suggests that the use of isotopic

Table 3: Canid stable isotope values from elsewhere in the Southwestern US/Northwestern Mexico.

Site, State (USA) or Country	Taxon	$\delta^{13}\text{C}_{\text{col}}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}_{\text{ap}}$	$\delta^{18}\text{O}$	Reference
Albert Porter Pueblo, Colorado	<i>Canis familiaris</i>	−7.7	10.4	–	–	Kemp et al. 2017
Albert Porter Pueblo, Colorado	<i>Canis familiaris</i>	−18.6	7.6	–	–	Kemp et al. 2017
Albert Porter Pueblo, Colorado	<i>Canis familiaris</i>	−8.6	8.2	–	–	Kemp et al. 2017
Albert Porter Pueblo, Colorado	<i>Canis familiaris</i>	−8.1	7.9	–	–	Kemp et al. 2017
Albert Porter Pueblo, Colorado	<i>Canis familiaris</i>	−8.9	10.6	–	–	Kemp et al. 2017
Grass Mesa Village, Colorado	<i>Canis familiaris</i>	−7.39	8.15	–	–	Kemp et al. 2017
Grass Mesa Village, Colorado	<i>Canis familiaris</i>	−7.28	9.32	–	–	Kemp et al. 2017
Grass Mesa Village, Colorado	<i>Canis familiaris</i>	−8.18	7.22	–	–	Kemp et al. 2017
Grass Mesa Village, Colorado	<i>Canis familiaris</i>	−8.03	8.26	–	–	Kemp et al. 2017
Lillian's Site, Colorado	<i>Canis familiaris</i>	−6.8	7.9	–	–	Kemp et al. 2017
Lillian's Site, Colorado	<i>Canis familiaris</i>	−8.7	10.2	–	–	Kemp et al. 2017
Lillian's Site, Colorado	<i>Canis familiaris</i>	−8.7	8.6	–	–	Kemp et al. 2017
Lillian's Site, Colorado	<i>Canis familiaris</i>	−8.6	8.1	–	–	Kemp et al. 2017
McPhee Pueblo, Colorado	<i>Canis familiaris</i>	−8.54	9.06	–	–	Kemp et al. 2017
McPhee Pueblo, Colorado	<i>Canis familiaris</i>	−7.63	10.21	–	–	Kemp et al. 2017
McPhee Pueblo, Colorado	<i>Canis familiaris</i>	−9.05	10.38	–	–	Kemp et al. 2017
McPhee Pueblo, Colorado	<i>Canis familiaris</i>	−6.96	12.61	–	–	Kemp et al. 2017
Yellow Jacket Pueblo, Colorado	<i>Canis familiaris</i>	−15.9	9	–	–	Kemp et al. 2017
Lone Kiva, New Mexico	"Dog"	−7.7	6.7	−4.4	−7.5	DeBoer and Tykot 2007
Pecos Pueblo, New Mexico	<i>Canis</i> sp.	−10.6	8.8	–	–	Spielmann et al. 1990
Costello-King, Arizona	<i>Canis familiaris</i>	−10.0	–	–	–	Ezzo and Stiner 2000
Sierra Blanca, Mexico	"Dog"	−11	9	–	–	Katzenberg and Kelley 1991 ¹
CH 254, Mexico	<i>Canis</i> sp.	−7.6	8.9	–	–	Webster and Katzenberg 2008

¹Values approximated based on published graphic.

values as a proxy for genetic identity in archaeological canids may, in at least some situations, be problematic. If in this case we had assumed that *Canis* sp. specimens with C_4 stable isotope dietary signatures were domesticated dogs, we would have misclassified samples AH4 and AH5 from Kiva J.

This does not, however, indicate that stable isotope studies on archaeological canids are not worthwhile. On the contrary, the overlap in prehistoric and modern dog, coyote and wolf diets suggests stable isotopes reflect variability in human-canid relationships – and that these relationships do not necessarily directly correspond with genetic patterns.

Context and the Arroyo Hondo canids

While all seven canid samples from Arroyo Hondo were recovered from domestic proveniences, these specimens vary in the specifics of their context, with some more suggestive of a close relationship with humans than others. Our isotopic values are similarly varied, but not in ways that one might expect.

AH4 and AH5 were originally identified as belonging to a "dog burial" within Kiva J, yet mtDNA indicates that genetically, AH4 is *Canis latrans*. However, the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$

values for samples AH4 and AH5 fell into ranges expected for a domestic dog, with $\delta^{13}\text{C}$ values at the lower end of values for the Arroyo Hondo samples (−14.4‰ and −14.3‰) and $\delta^{15}\text{N}$ values with a much lower trophic level than any of the other samples (both 6.3‰). We do note that, while there was variation in $\delta^{13}\text{C}_{\text{ap}}$ from these samples (0.8‰), we suspect this indicates either fractionation differences between elements or diagenetic effects, since both contextual evidence and $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values suggest these bones derive from one individual.

Specimens AH4 and AH5, then, indicate that at least some coyotes may have had a special role for Arroyo Hondoans. There is precedent elsewhere in the Americas for such a situation: in the Great Basin, the Ute were known to keep tamed coyotes (Stewart 1942), as were some groups in the Pacific Northwest Coast (Norton 1985). Prehistoric hybrid wolf-dogs from Teotihuacan may have been fed largely herbivorous diets to suppress aggression (Valadez 2006). If Arroyo Hondoans kept or tamed coyotes then we expect stable isotope values from these animals to match those from domesticated dogs – as is the case for specimens AH4 and AH5 (Table 2).

In addition, AH7, identified as *Canis* sp. based on genetics and morphology, has a $\delta^{13}\text{C}$ value that falls within the expected range for Southwest coyotes, but has an enriched $\delta^{15}\text{N}$ value (13.4‰). Enriched $\delta^{15}\text{N}$ values in canids typically indicate higher trophic level feeding, either from access to quality meat sources, consuming human feces or scraps, or due to nursing (Guiry 2012); such enrichment may also indicate nutritional stress (see Hobson et al. 1993). The Arroyo Hondo sample did contain three specimens labeled as juveniles, but AH7 was not one of those (the specimens that were identified as juvenile had $\delta^{15}\text{N}$ values in line with the rest of the samples, ranging from 8.5‰ to 9.3‰). Therefore, it is likely that the diet of AH7 reflects a human-domestic dog relationship during life; this canid likely had access to human hunting and food scraps, or waste. This conclusion is further strengthened by this specimen's burial treatment within a roomblock, which is a more personal and familial area as compared to a ceremonial kiva or community plaza.

Conversely, two other specimens identified through mtDNA analysis as coyotes (AH1 and AH2; Kemp et al 2017) have $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values reflecting a diet similar to other prehistoric coyotes in the Southwest, despite having been recovered from Plaza G and a kiva, respectively. While some coyotes at Arroyo Hondo were treated in special ways, others seem to have been more typical wild canids.

Dogs vs. turkeys

The other domestic animal at Arroyo Hondo – turkeys – appear to have been managed in very different ways than the Arroyo Hondo canids. The Arroyo Hondo turkeys belonging to the Southwestern domestic lineage (aHap1) exhibit low-variance $\delta^{13}\text{C}$ values in the range of

C_4 plants (Figure 4; see Conrad et al. 2016; Kemp et al. 2017). In addition, osteometric evidence for broken and healed bones among the turkeys and the presence of turkey pens indicate that turkeys at Arroyo Hondo had restricted mobility, controlled diets, and extensive care by the humans with whom they lived (Fothergill 2016; Lang and Harris 1984).

This record contrasts with that of the Arroyo Hondo canids. Stable isotope values show that most of these had access to a range of C_3 and C_4 resources both for protein and carbohydrates/lipids. In one case (specimen AH6), an individual canid appears to have primarily accessed its protein from a C_4 -dominant source. This source could have been turkey meat. Dogs eating meat from turkeys that consumed C_4 plant foods would exhibit enriched C_4 bone collagen protein stable isotope values, as AH6 does.

Conclusions

The Arroyo Hondo canids suggest a disjuncture between archaeological definitions of domestication and how Ancestral Puebloans considered dogs. In some of the specimens we tested, dogs match archaeological expectations for dogs, but in others coyotes seem to have been treated like dogs, and in yet others genetically domestic dogs seem to have eaten more like coyotes or wolves. In addition, the burial locations of the canids examined here suggest an after-life role for all of these individuals. Their proximity to architecture, despite the variability in genetics and life-time dietary patterns, is key to understanding the relationships they had with humans, both before and after life.

These data, taken together, provide a cautionary tale about over-reliance on any one line of evidence in

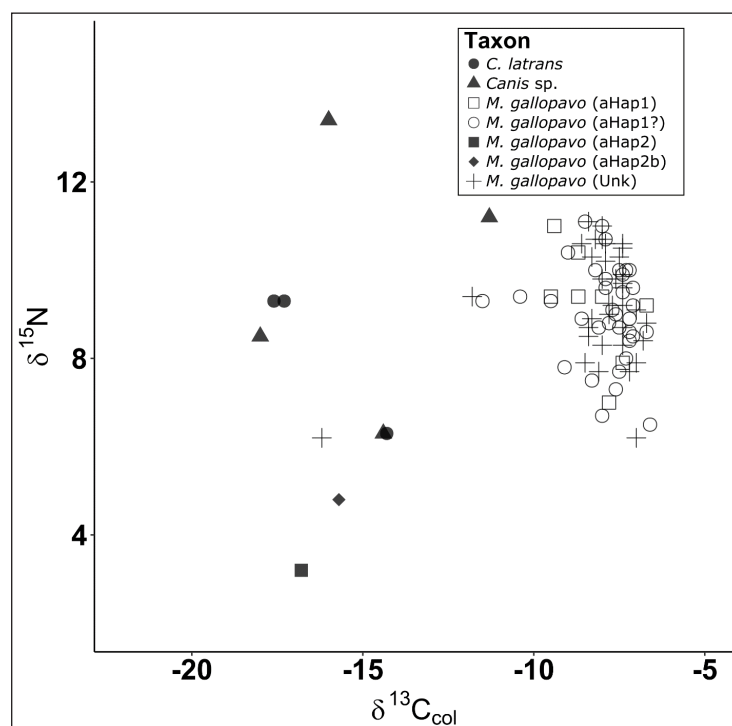


Figure 4: Collagen-derived $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of the canid specimens analyzed in this study and turkeys from Conrad et al. (2016).

identifying domestic animals. More importantly, they suggest that Arroyo Hondoans may have defined “dog” differently than present-day domestication researchers do – and that the use of multiple lines of evidence, including zooarchaeological, genetic, isotopic, contextual, and ethnographic, can provide a rich and more accurate understanding of past human-canid relationships.

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Competing Interests

The authors have no competing interests to declare.

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